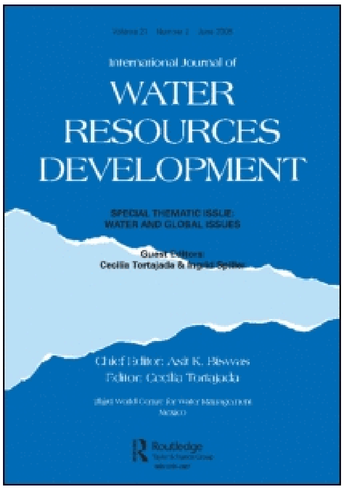

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Economic and Conservation Tradeoffs of Regulatory vs. Incentive-based Water Policy in the Pacific Northwest

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ABSTRACT *In this paper, onfarm water conservation and agricultural economic trade-offs between selected regulatory and conservation-incentive water-policy choices are evaluated for the Pacific Northwest. Five broad water-policy perspectives are analysed using a total of 37 alternative policy scenarios. Policy analyses use a primal/dual-based, multi-product, normalized restricted-equilibrium model of Pacific Northwest field-crop agriculture. Results demonstrate that conservation-incentive water policy, when integrated within balanced policy reform, can produce upwards of 1.7 million acre-feet of onfarm conserved water for the region, while also significantly increasing economic returns to farmers. Producer willingness to accept water-policy change is lowest for regulatory policy (US\$4–\$18 per acre-foot of conserved water), but highest for conservation-incentive policy that increases both irrigation efficiency and crop productivity (\$67–\$208 per acre-foot of conserved water). Conservation-incentive water policy also enhances decision-maker flexibility in meeting multiple regional policy goals (i.e. water for endangered aquatic species, water quality, Native American treaty obligations, and sustainable rural agricultural economies).*

Introduction

The intensity of competition for water resources across the western United States continues to heighten significantly. The competition for this scarce resource is ever more the result of increased water demands for both human and ecological needs, with both increasingly requiring quality water supplies for a growing urbanized society, wildlife habitat, the protection and recovery of threatened and endangered aquatic species, and Native American treaty obligations. This human/species/water quality water-resource conflict is nowhere more intense than in the Pacific Northwest (PNW). The conflict here is due to competing demands for Columbia and Snake River Basin water resources across hydro-power, recreation, agriculture, water quality, threatened and endangered anadromous salmon species, and Native American treaty fishing rights. Agriculture is at the centre of the debate in this conflict because agriculture holds claim to about 96% of the region's consumptive water use (Solley *et al.*, 1998), and is recognized as the dominant non-point source of chemical-based contamination of both surface and groundwater supplies (IDEQ, 1997; Clark *et al.*, 1998; Wentz *et al.*, 1998; Williamson *et al.*, 1998).

Development of water resources for agriculture in the PNW has had a

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detrimental impact on the anadromous fish species of the region (NMFS, 1995, 1998, 1999; Willis & Whittlesey, 1998). Adult salmonid migrate upstream and juveniles (smolts) migrate out to sea just at a time when diversions for irrigated agriculture are at their greatest. Post-development Snake River flows at Brownlee Reservoir during peak irrigation season (May–July) average only 57% of pre-development flows (NMFS, 1999). Consumptive use alone in the Upper Snake Basin is responsible for reducing annual inflows to Brownlee Reservoir by 33% (USBR, 1998). Finally, it is also believed that non-point-source contamination from upper Basin irrigated agriculture (surface and groundwater) is a significant contributing factor in the decline of salmon species (IDEQ, 1997; Clark *et al.*, 1998; NMFS 1999).

Ultimately, the solution to this regional resource conflict is expected to involve a reallocation of water resources from agriculture through regulatory, market transfers, and/or conservation-incentive policy choices. Several PNW studies have examined various economic and conservation merits of several water-policy perspectives using alternative analytic approaches. Bernardo *et al.* (1987) integrated biophysical crop-growth models with a representative-farm, mathematical-programming irrigation management model for the Columbia River Basin to evaluate optimal intra-seasonal farm allocation of restricted water supplies. Turner & Perry (1997) used a stochastic-programming with recourse approach to account for the uncertainty of water supplies on farm-level irrigation management, and to assess producer willingness to participate in an instream-flow, water-lease market within Oregon's Deschutes River Basin. Willis *et al.* (1998) integrated a probability model of upper Snake River flows, a reservoir hydrology model, and farm-level, mathematical-programming irrigation management models to assess the economics and potential of using contingent water-market contracts to augment lower Snake River streamflows to enhance salmon migration in low-flow years. Willis & Whittlesey (1998) integrated streamflow and groundwater hydrology models with representative-farm, chance-constrained programming models to examine streamflow augmentation potential of restricted agricultural diversions, additional upstream storage, increased agricultural water-use efficiency, and intrabasin water transfers for the Walla Walla River Basin in south-eastern Washington. While each of these studies has made a unique contribution to the PNW water policy debate, these studies view the merits of policy change only from a representative-farm, irrigation management perspective.

Shumway *et al.* (1984), and Chambers & Just (1989) have demonstrated that agricultural-based, resource policy analysis must capture both resource input and output substitution possibilities within the same economic framework, thereby simultaneously considering the economic adjustment costs of both substitution possibilities. In addition, to effectuate water policy change, the policy analysis must also evaluate the economic and conservation tradeoffs of alternative policy perspectives from the point of view of various levels of policy implementation, and evaluate tradeoffs for policy change that simultaneously encompasses multiple-policy perspectives for multiple-policy goals. As revealed in a recent pastoral report by PNW Catholic Bishops on the PNW water conflict, pending policy decisions need to reflect a shared sacrifice across multiple policy goals (Crampton, 1999).

This paper extends and integrates previous work by Schaible *et al.* (1995) and Schaible (1997) to evaluate selected regulatory and conservation water-policy choices for the PNW using economic and onfarm water conservation tradeoff curves. Alternative policy choices are evaluated both singularly and in combination to reflect a policy focus integrating multiple policy goals. More specifically, a primal/dual-based, multiproduct, normalized restricted-equilibrium model of PNW field-crop agriculture is used to: (1) assess the economic-opportunity value of conserved water to agriculture for alternative regulatory and conservation-incentive water-policy choices by simultaneously endogenizing both resource and output substitution possibilities within the economic objective function; and (2) contrast (using tradeoff curves) both the onfarm water conservation and the economic gain or cost to PNW agriculture of alternative water policy choices. Economic gains or losses will identify agriculture's minimum willingness-to-accept values across policy alternatives. The paper will then summarize policy results and their implications for PNW water policy change.

Economic Model

Because of institutional and farm-level rigidities, land and water resources for agricultural producers are considered fixed and allocatable resources (Shumway *et al.*, 1984; Moore & Negri, 1992; Schaible, 1997). This means that the analytical framework must take this into account by endogenizing the opportunity (adjustment) costs of farm-level resource-allocation decisions within an economic objective function used to assess changes in producer economic returns for alternative water-policy choices. In this analysis, this is accomplished using a primal-dual, quadratic specification of a multiproduct, normalized restricted-equilibrium model of PNW field-crop production systems, estimated within the context of a multistage, programming-based system estimation procedure (Schaible, 1997).

The model's three-stage programming system for a single modelling subarea (MSA) is expressed in general form in Figure 1. The three-stage system ensures that, given a policy-imposed change, the stage-two policy model will assess production response consistent with producer optimal long-run equilibrium, although conditional on fixed and allocatable land and water resources. Crop production technologies are defined for Bureau of Reclamation (BoR) water-supplied irrigation (z_i^b), private water-supplied irrigation, (z_j^p), and non-irrigated (dryland) crop production (x_r^d). The parameter P^o identifies the vector of crop prices, while $\bar{C}_i^b$, $\bar{C}_j^p$, and $\bar{C}_r^d$ identify observed-equilibrium total average variable costs for BoR (b) and privately supplied (p) irrigation and dryland (d) production technologies, respectively. Water-yield relationships per irrigated acre (y) are MSA-simulated, reduced-form quadratic functions of applied water rates w_i^b and w_j^p. Expressed in general form as $y = \mathrm{f}(w) = \beta_1 + \beta_2 w + \beta_3 w^2$, these relationships were derived from econometrically estimated longer-form yield functions (Moore *et al.*, 1992). Dryland yields, $\bar{y}_r^d$, are assumed constant (exogenous).

Constraint vectors $\bar{e}$ and $\bar{\phi}$ in Figure 1 identify output-specific Euclidean-normalization constraints $\bar{\eta} w \geq \bar{y}$ and $f(w)/\bar{w} \leq \bar{\phi}$, where $\bar{\eta}$ and $\bar{\phi}$ are observed-equilibrium measures of output per unit water applied and upper-bound yield productivity, respectively. These normalization constraints identify output-specific technologies by transforming their input–output correspondences at observed equilibrium into a unitary distance function (Afriat, 1972; Färe & Shephard, 1977; Gorman, 1985). This vector of unitary values, represented

Stage I model: the normalized restricted-profit function specification

Objective function:

$$\max_{\substack{W_1^b,\ldots,W_M^b\\ W_1^p,\ldots,W_N^p\\ Z_1^b,\ldots,Z_M^b\\ Z_1^p,\ldots,Z_N^p\\ X_1,\ldots,X_R}} \Pi = \sum_{i=1}^{M} P_i^o\left[\beta_{1i} + \beta_{2i} w_i^b + \beta_{3i}(w_i^b)^2\right] z_i^b + \sum_{j=1}^{N} P_j^o\left[\beta_{1j} + \beta_{2j} w_j^p + \beta_{3j}(w_j^p)^2\right] z_j^p + \sum_{r=1}^{R} P_r^o \bar{y}_r^d x_r^d - \sum_{i=1}^{M} \bar{C}_i^b z_i^b - \sum_{j=1}^{N} \bar{C}_j^p z_j^p - \sum_{r=1}^{R} \bar{C}_r^d x_r^d$$

Subject to constraint sets for: $\bar{e} \pm \epsilon$; $\bar{\phi} \pm \epsilon$; $\bar{H} \pm \epsilon$; $\bar{H}^b \pm \epsilon$; $\bar{Z} \pm \epsilon$; $\bar{Z}^b \pm \epsilon$; $\bar{L} \pm \epsilon$

Plus output-specific, observed-equilibrium constraints:

$$z_i^b \ \overset{<}{\underset{>}{-}}\ \bar{z}_i^b \pm \epsilon \qquad z_j^p \ \overset{<}{\underset{>}{-}}\ \bar{z}_j^p \pm \epsilon \qquad x_r^d \ \overset{<}{\underset{>}{-}}\ \bar{x}_r^d \pm \epsilon.$$

Stage II model: the normalized restricted-equilibrium model specification

Objective function:

$$\max_{\substack{W_1^b,\ldots,W_M^b\\ W_1^p,\ldots,W_N^p\\ Z_1^b,\ldots,Z_M^b\\ Z_1^p,\ldots,Z_N^p\\ X_1,\ldots,X_R}} \Pi = \sum_{i=1}^{M} P_i^o\left[\beta_{1i} + \beta_{2i} w_i^b + \beta_{3i}(w_i^b)^2\right] z_i^b + \sum_{j=1}^{N} P_j^o\left[\beta_{1j} + \beta_{2j} w_j^p + \beta_{3j}(w_j^p)^2\right] z_j^p + \sum_{r=1}^{R} P_r^o \bar{y}_r^d x_r^d$$

$$- \sum_{i=1}^{M} \left[\alpha_i^b z_i^{\,b} + .5\gamma_i^b (z_i^{\,b})^2 \right] - \sum_{j=1}^{N} \left[\alpha_j^p z_j^{\,p} + .5\gamma_j^p (z_j^{\,p})^2 \right] - \sum_{r=1}^{R} \left[\alpha_r^d x_r^{\,d} + .5\gamma_r^d (x_r^{\,d})^2 \right]$$

Subject to constraint sets for: $\bar{e}$, $\bar{\phi}$, $\bar{H}$, $\bar{H}^b$, $\bar{Z}$, $\bar{Z}^b$, $\bar{L}$.

Stage III model: the linearized-quadratic specification of stage II (Based on Takayama and Judge's reducibility theorem)

Objective function:

$$\underset{\substack{W_1^b,\ldots,W_M^b \\ W_1^p,\ldots,W_N^p \\ Z_1^b,\ldots,Z_M^b \\ Z_1^p,\ldots,Z_N^p \\ X_1,\ldots,X_R}}{Max\ \Pi} = \sum_{i=1}^{M} P_i^{\,o} \bar{Y}_i^{\,b} z_i^{\,b} + \sum_{j=1}^{N} P_j^{\,o} \bar{Y}_j^{\,p} z_j^{\,p} + \sum_{r=1}^{R} P_r^{\,o} \bar{Y}_r^{\,d} x_r^{\,d} - \sum_{i=1}^{M} \left[\alpha_i^b z_i^{\,b} + (\gamma_i^b \bar{z}_i^{\,b}) z_i^{\,b} \right]$$

$$- \sum_{j=1}^{N} \left[\alpha_j^p z_j^{\,p} + (\gamma_j^p \bar{z}_j^{\,p}) z_j^{\,p} \right] - \sum_{r=1}^{R} \left[\alpha_r^d x_r^{\,d} + (\gamma_r^d \bar{x}_r^{\,d}) x_r^{\,d} \right]$$

Subject to constraint sets for: $\bar{e}$, $\bar{\phi}$, $\bar{H}$, $\bar{H}^b$, $\bar{Z}$, $\bar{Z}^b$, $\bar{L}$.

Figure 1. A multi-stage, quadratic-programming estimation system for a multiproduct, normalized restricted-equilibrium model of PNW field-crop agriculture.

by $[\bar{e}_i^b,\ \bar{e}_j^p,\ \bar{e}_r^d] = [\bar{\eta}_i^b w_i^b \mid f_i^b(\bar{w}_i^b),\ \bar{\eta}_j^p w_j^p \mid f_j^p(\bar{w}_j^p),\ 1] = \bar{e} = [1,\ 1,\ 1]$, reflects each technology's normalized efficiency of fixed and allocatable factors. However, these values do not mean that irrigators are operating at 100% water-use efficiency, rather, as scalar values, they define an aggregate normalized-efficiency reference per production technology. The purpose of normalization is to ensure that the model endogenously allocates fixed resources consistent with profit-maximizing, ray-homothetic expansion paths for each production technology (Färe & Shephard, 1977). For policy analysis, these normalized-efficiency parameters may range from zero to unity, thereby allowing for analysis of public policy choices encouraging onfarm technical change (such as programmes encouraging adoption of water-conserving irrigation technology).

Constraints $\bar{H}$, $\bar{H}^b$, $\bar{Z}$, $\bar{Z}^b$, *and* $\bar{L}$ in Figure 1 capture MSA-level resource fixity for land and water resources, where total water supply at the farmgate, $\bar{H}$, includes BoR-supplied water, $\bar{H}^b$, and total privately-supplied water $\bar{H}^p$. Private water supplies at the farmgate consist primarily of groundwater, but may also include privately supplied onfarm and off-farm surface water. MSA-level total cropland, $\bar{L}$, consists of total irrigated land, $\bar{Z}$ (which includes total BoR-irrigated land, $\bar{Z}^b$, and total private irrigated land, $\bar{Z}^p$), and total dryland $\bar{X}$.

Stage one of the programming system is specified as a multi-output, normalized, restricted-profit function model. This stage of the modelling system is used to estimate output-specific, temporary or 'disequilibrium' opportunity values of fixed resources, $\bar{\lambda}^* = [\bar{\lambda}_i^*,\ \bar{\lambda}_j^*,\ \bar{\lambda}_r^*]$, evaluated for each of the output-specific observed-equilibrium constraints. These fixed-resource opportunity values, which reflect short-run economies of scope measuring the difference between short-run marginal and average costs, are used to define output-specific, implicit total economic-cost functions for the stage two model. Total economic-cost functions, identified in general form, are specified as $\psi(\mathrm{z}) = \alpha\mathrm{z} + 0.5\gamma(\mathrm{z})^2$ for irrigated crops, and $\psi(\mathrm{x}) = \alpha\mathrm{x} + 0.5\gamma(\mathrm{x})^2$ for dryland crops.

Total economic-cost function coefficients will differ depending upon whether $\bar{\lambda}^* \geq 0$ or $\bar{\lambda}^* < 0$. For a quadratic cost-function specification, Schaible (1997) demonstrates that for irrigated production technologies, when $\bar{\lambda}^* \geq 0$, the coefficient vector $[\alpha\ \gamma] = [(\bar{C} - |\bar{\lambda}^*|)\quad (2|\bar{\lambda}^*|/\bar{z})]$, and when $\bar{\lambda}^* < 0$, then $[\alpha\ \gamma] = [(\bar{C} - 3|\bar{\lambda}^*|)\quad (2|\bar{\lambda}^*|/\bar{z})]$. (Similar relationships exist for dryland production technologies.)

The stage-two model of the programming system is a long-run, multi-output, normalized restricted-equilibrium specification (Squires, 1987), which replaces observed-equilibrium accounting costs, $\bar{C}z$ and $\bar{C}x$, with the output-specific implicit total economic-cost functions (Figure 1). In addition, the stage-two specification requires only the normalization and MSA-level observed-equilibrium resource constraints. Given reliable estimates of the total economic-cost function parameters, the normalized restricted-equilibrium specification no longer requires output-specific resource restrictions. The total economic-cost coefficients will characterize optimal solutions consistent with competitive profit maximization without output-specific restrictions.

To ensure a system's approach to estimating reliable economic-cost function coefficients, three test criteria are applied. For the first, stage three of the programming system applies Takayama and Judge's Reducibility Theorem to the stage two model. This theorem says that a quadratic optimization model, when linearized for an observed equilibrium, reproduces that observed equilibrium. Second, consistent with competitive equilibrium assumptions and regularity conditions, the cost-structure transformations for the stage-two model must produce positive increasing economic-cost functions for each production technology, that is, positive average and marginal economic costs. Third, ratios of the optimal solution values to observed-equilibrium values must equal 1.0 ± 0.02 for each model stage. Calibration adjustments, $\pm \varepsilon$, are applied to resource and output-specific constraints in the stage one model (Figure 1) until all system test criteria are met. The stage-three linearized version of the stage-two model, when applied jointly with all three tests, ensures a unique estimate of $\bar{\lambda}^*$, given the estimated water-yield relationships and the quadratic functional form of the profit function. For estimates of $\bar{\lambda}^*$, the stage-two model will then endogenize a true *ex post* measure of each technology's marginal economic-cost adjustment, $\frac{\delta \psi}{\delta z} = \lambda^{**}$, both at observed-equilibrium and when applying the stage-two model to evaluate a resource-policy change. Marginal economic (adjustment) costs to policy change will not be influenced by the intercepts of the economic-cost functions, but will depend only on the values of the slopes of the water-yield functions and the equilibrium resource endowment. Hence, these values will be invariant to the calibration adjustments.

PNW Agriculture and its Resource Environment

Irrigated agriculture is a substantial component of PNW agriculture. Harvested irrigated cropland for 1997 accounted for 48.4% of 12.5 million acres of total harvested cropland (50.5% in Idaho, 23.3% in Oregon, and 26.2% in Washington) (NASS, 1999). Nearly 52% of all farms in the region irrigated some crop (68, 45 and 45% in Idaho, Oregon and Washington, respectively). Of the total market value of agricultural products sold in 1997 ($11.1 billion), farms with any irrigation accounted for 74.7% of the total. For the region, irrigated alfalfa acres dominates the irrigated cropping pattern (at 22.1%), followed by irrigated wheat (18.5%), potatoes (9.3%), barley for grain (7.2%), fruits and nuts (6.2%), orchard crops (5.5%), and vegetables (5.1%) (with all other irrigated crops at less than 4% each). The irrigated cropping pattern (for 1997), however, varies across the region, with higher-valued crops (fruits and nuts, orchards, vegetables, hops, berries, and mint for oil) accounting for 44.3% of irrigated crop acres in Washington, 23.9% in Oregon and only 2.7% in Idaho. In Idaho, irrigated wheat, alfalfa hay and barley for grain account for 63.3% of irrigated crop acres (potatoes account for an additional 12.8%).

Irrigated agriculture also accounts for 80.6% of total PNW freshwater withdrawals (28.8 out of 35.7 million acre-feet for 1995) (Solley *et al.*, 1998). Idaho accounts for most PNW withdrawals for agriculture (50.8%), with Oregon and Washington withdrawals nearly equal at 24.0 and 25.2%, respectively. Surface water is the dominant source for agriculture, accounting for 83.7% of total withdrawals for agriculture (at 24.1 million acre-feet). Most of these withdrawals occur in Idaho (49.0%). Idaho also accounts for 59.7% of PNW groundwater withdrawals for agriculture (4.7 million acre-feet for the region).

Policy Options Evaluated and Data Sources

This study analysed the farm-level economic and conservation impacts for 37 policy scenarios examined under five broad regulatory or conservation-incentive

Table 1. Water-policy perspectives evaluated for the Pacific Northwest

Single-policy options	Scenario descriptions			
(A) A general irrigation technical-change policy focus (constant yield)	7 scenarios increase onfarm irrigation efficiency (across all irrigated field crops) ranging from 5% to 20% in 2.5% increments			
(B) A reduced BoR diversion (regulatory) policy focus	7 scenarios reduce MSA-level BoR-supplied water to agriculture ranging from 5% to 20% in 2.5% increments			
(C) A BoR water-price policy focus	15 scenarios increase onfarm, purchased BoR-water costs ranging from 5% to 40% in 2.5% increments			
	Scenarios			
Policy-mix options	1	2	3	4
(D) A BoR policy-mix focus				
Simultaneous policy changes:	% change in policy parameters			
(i) Reduced MSA-level BoR diversions to agriculture	5	10	15	20
(ii) Increased farm-level, purchased BoR-water cost	5	10	20	30
(iii) Increased off-farm conveyance efficiency of BoR-supplied water	5	10	20	30
(E) A resource-efficiency policy-mix focus				
Simultaneous policy changes:	% change in policy parameters			
(i) Increased farm-level, purchased BoR-water cost	5	10	15	20
(ii) Increased off-farm conveyance efficiency of BoR-supplied water	5	10	15	20
(iii) Increased onfarm irrigation efficiency (for all irrigated crops)	5	10	15	20
+ % yield increases of:	2	4	5	6

water-policy perspectives (Table 1). Three of these policy perspectives involve a single policy focus, of which two represent a conservation-incentive policy focus (options A and C), and one represents a regulatory policy focus (option B). The two remaining policy perspectives each simultaneously impose a mix of policy choices (options D and E).

For policy perspective (A), seven scenarios simulate constant-yield, factor-reducing, irrigation technical change by increasing onfarm irrigation efficiency across all irrigated field crops ranging from 5% to 20% (in 2.5% increments). Crop yields were held constant for this set of policy scenarios in order to isolate irrigation efficiency effects alone. For policy perspective (B), seven policy scenarios reflect a regulatory policy focus by imposing reductions in MSA-level publicly supplied (BoR) water to agriculture ranging from 5% to 20% (in 2.5% increments). For policy perspective (C), 15 policy scenarios simulate a BoR water-price policy focus by increasing onfarm, purchased BoR-water costs ranging from 5% to 40% (in 2.5% increments). For policy perspective (D), four policy scenarios simulate a BoR policy-mix focus where each scenario simultaneously imposes changes in three different policy instruments. These four scenarios simultaneously evaluate: (i) reduced MSA-level BoR diversions to agriculture (by 5, 10, 15 and 20% respectively); (ii) increased farm-level purchased BoR-water costs (by 5, 10, 20 and 30% respectively); and (iii) increased off-farm conveyance efficiency of MSA-level BoR-supplied water to agriculture (by 5, 10, 20 and 30% respectively). For policy perspective (E), four policy scenarios simulate a resource-efficiency policy-mix focus where each scenario simultaneously evaluates: (i) increased farm-level purchased BoR-water costs (by 5, 10, 15 and 20% respectively); (ii) increased off-farm conveyance efficiency of BoR-supplied water (by 5, 10, 15 and 20% respectively); and (iii) output enhancing, increased onfarm irrigation efficiency across all irrigated field crops (by 5, 10, 15 and 20% respectively). In this case, increased onfarm irrigation efficiency is assumed to be both factor reducing and output enhancing, that is, to increase crop yields across the four scenarios by 2, 4, 5 and 6% respectively.

Land and water resources used for 93 irrigated and 34 non-irrigated (dryland) production technologies (for up to nine field crops) were identified for 11 MSAs across Idaho (3), Oregon (4), Washington (2), and one MSA each in northwest Montana and Wyoming. MSAs reflect state and hydrologic boundaries, defined on the basis of county-line approximations of major watershed divisions. Irrigated and dryland crop production technologies were defined for alfalfa hay, corn for grain, dry beans, other hay (other than alfalfa), potatoes, sugar beets, small grains (barley, oats and rye), silage and wheat.

Drawing upon the database defined in Schaible (1997), various county-level resource data were assembled and aggregated to the MSA level. In addition, crop-production costs were generated using USDA/Economic Research Service farm-level data sets supplemented with information from State crop-enterprise budget reports, USDA's Farm and Ranch Irrigation Survey (FRIS), and data files from USDA's Natural Resource Conservation Service. Land and water-resource data were taken from FRIS, Bureau of Reclamation, and US Census of Agriculture sources. Model implementation used the General Algebraic Modeling System (GAMS), release 2.25, version 92.

Policy Results

Onfarm water conservation and economic impacts for the five policy perspectives analysed are summarized in Figures 2–7. Only policy impacts associated with PNW field-crop agriculture are reported. Owing to space limitations, similar results at the state and crop level could not be presented here. However, Figures 8 and 9 do present state-specific results identifying producer minimum willingness-to-accept values for conservation policy designed to increase onfarm irrigation efficiency (policy option A) and for a resource-efficiency policy-mix focus (policy option E).

For this study, onfarm water conservation for the policy options analysed refers to reduced onfarm applied water or reduced diversions from surface and/or groundwater sources. These agricultural water savings account for reduced onfarm water use associated with both resource and output substitution possibilities, that is, substituting land and water resources to produce more crops that consume less water and fewer of the water-intensive crops, reducing surface-water use and increasing groundwater use (where groundwater irrigation already exists), shifting from irrigated to dryland crop production, and reducing total cropland production. However, reduced surface-water diversions associated with agricultural water conservation do not necessarily imply streamflow augmentation downstream. Any downstream flow gain due to onfarm conservation of surface-water use will depend upon tradeoffs with downstream return-flow losses occurring during the irrigation season, which are influenced by aquifer and soils characteristics, farm runoff volume, and evaporative losses. Schaible *et al.* (1995) illustrate that increased onfarm irrigation efficiency can induce streamflow augmentation downstream when the aquifer return flow during the irrigation season is relatively low. In addition, conserved surface water generally will also include water from permanent losses (due to deep aquifer seepage and evaporation) and the portion of return flow that would not have occurred during the irrigation season. Finally, crop and resource substitution effects will also reduce crop consumptive-use requirements from surface-water sources. All these effects mean that conserving onfarm surface-water use can potentially contribute to streamflow augmentation downstream. The results here, however, do not measure streamflow augmentation downstream, they refer only to agricultural water conservation at the farm level.

Regional Onfarm Water Savings

Figures 2 and 3 indicate that significant regional tradeoffs exist in onfarm water conservation between water policy choices, but also that water policy reform could generate significant agricultural water savings. A regulatory policy that would reduce BoR surface water diversions across the PNW by 5% or 20% (205.0 or 820.0 thousand acre-feet, respectively) results in reduced onfarm water use of 155.0 or 619.0 thousand acre-feet, respectively (Figure 2). About 59% of this conservation burden, however, would occur in Idaho, which accounts for nearly half of the surface water withdrawals for irrigation for the region. Results for this policy choice reflect that producers minimize their economic losses by reducing their use of BoR-supplied water, and then reallocate their remaining water supplies across alternative crops, while also increasing dryland crop production. Regulatory policy, then, induces producers to emphasize significant crop substitution, rather than resource substitution. A conservation-incentive policy focus that induces increased onfarm irrigation efficiency (adoption of water-conserving irrigation technologies and water management) would generate a nearly equivalent amount of conservation of publicly supplied water as would a regulatory approach. However, onfarm irrigation technical-change policy would also generate significant onfarm conserved groundwater, with total conservation for the PNW ranging from 377.0 thousand to over 1.8 million acre-feet (Figure 2), for policy that would increase onfarm irrigation efficiency ranging from 5% to 20%, respectively, across PNW irrigated field-crop agriculture. About 49.1% of the regional conservation burden of a 20% induced onfarm irrigation technical change would originate in Idaho. Producers would respond to a technical-change/conservation policy focus by reducing both surface and groundwater use, but also by reducing irrigated small grains and wheat acreage and increasing acres of irrigated alfalfa and sugar beets.

For a water-price policy focus, increases in onfarm purchased water costs from 5% to 20% would result in no net water conservation because producers substitute groundwater for surface water. However, for the region as a whole, conserved BoR-supplied water would range from 58.0 to 235.0 thousand acre-feet. Figure 2 illustrates that because agriculture's demand for water is price inelastic, it would take a water price increase of at least 50.0% to acquire an equivalent amount of conserved BoR-supplied water as either a regulatory or an irrigation technical-change policy.

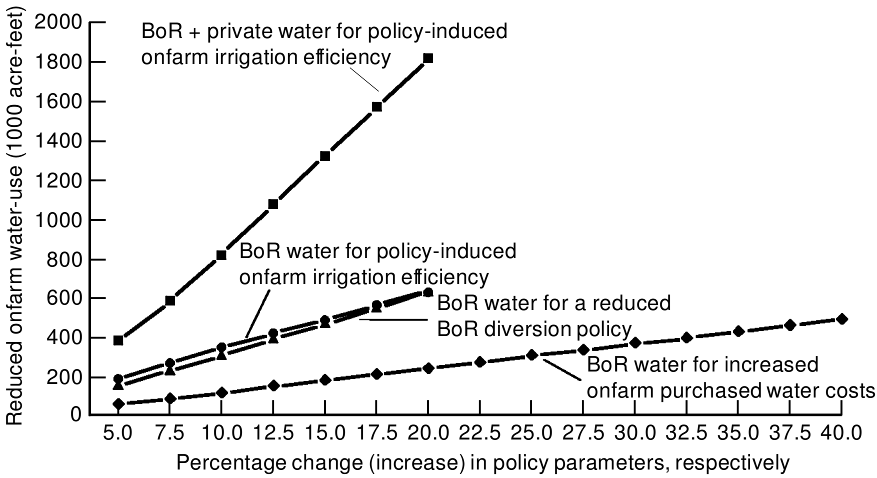

Figure 2. Reduced onfarm water use: regulatory versus conservation-incentive water policy choices, Pacific Northwest. *Key*: ■, ● onfarm irrigation deficiency; ◆ onfarm purchased water cost; ▲ reduced BoR diversions.

Figure 3 illustrates that water policy reform with integrated multiple-policy choices would also generate significant onfarm water conservation. A resource-efficiency policy mix (options E1-E4) emphasizes conservation of both surface water and groundwater, and would result in significantly larger total onfarm conservation than a BoR policy mix (options D1–D4), ranging from 154.0 and 370.0 thousand acre-feet for options D1 and E1, respectively, to 672.0 thousand and 1.73 million acre-feet for options D4 and E4, respectively. Both policy-mix options involve additional off-farm water conservation (not included in Figure 3) due to increased conveyance efficiency of BoR-supplied water, ranging from 48.0 and 50.0 thousand acre-feet for options D1 and E1, respectively, to 240.0 and 200.0 thousand acre-feet for options D4 and E4, respectively. Mixed-policy options, however, have the added advantage of inducing a shared conservation burden for agriculture across producers dependent upon alternative water sources, between producers and water retailers or wholesalers (irrigation districts or the BoR), as well as among production regions.

Regional Agricultural Economic Impacts

Figures 4 and 5, together with Figures 2 and 3, illustrate that significant onfarm water conservation can be acquired at either minimal economic cost to PNW agriculture, or for substantial economic gain, depending on the policy focus. A regulatory policy is more costly to agriculture than a similarly imposed BoR water-price policy (Figure 4). A BoR policy-mix option, however, is the most costly to agriculture (Figure 5). Even so, economic losses to PNW agriculture would range from only $5.1 million for a 20% increase in onfarm costs for BoR-supplied water, to $8.5 million for policy that reduces by 20% BoR-supplied water to field-crop agriculture, to $15.7 million for the more stringently simulated BoR policy-mix option (D4) (Figures 4 and 5). However, when water policy reform encompasses irrigation technical change (increased irrigation efficiency), significant onfarm water conservation can coincide with modest to substantial

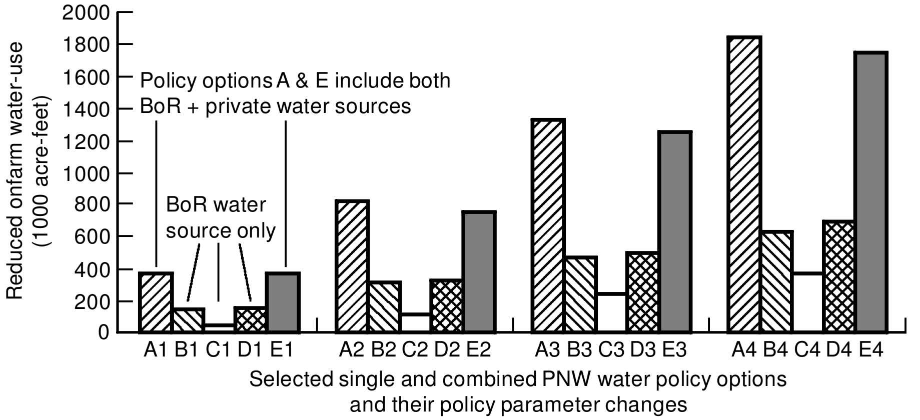

Figure 3. Reduced onfarm water use: selected single and combined water policy options, Pacific Northwest.

Note: Policy parameter changes:

Increased onfarm irrigation efficiency (Only):	A1 = 5%;	A2 = 10%;	A3 = 15%;	A4 = 20%
Reduced BoR diversions:	B1 = 5%;	B2 = 10%;	B3 = 15%;	B4 = 20%
Increased onfarm purchased water costs:	C1 = 5%;	C2 = 10%;	C3 = 20%;	C4 = 30%

BoR policy mix options:

D1 = 5% reduced BoR diversions; 5% increased BoR conveyance efficiency; 5% increased onfarm BoR water cost.

D2 = 10% reduced BoR diversions; 10% increased BoR conveyance efficiency; 10% increased onfarm BoR water cost.

D3 = 15% reduced BoR diversions; 20% increased BoR conveyance efficiency; 20% increased onfarm BoR water cost.

D4 = 20% reduced BoR diversions; 30% increased BoR conveyance efficiency; 30% increased onfarm BoR water cost.

Resource efficiency policy mix options:

E1 = 5% increased irrigation efficiency + 2% increased yield; 5% increased BoR conveyance efficiency; 5% increased onfarm BoR water cost.

E2 = 10% increased irrigation efficiency + 4% increased yield; 10% increased BoR conveyance efficiency; 10% increased onfarm BoR water cost.

E3 = 15% increased irrigation efficiency + 5% increased yield; 15% increased BoR conveyance efficiency; 15% increased onfarm BoR water cost.

E4 = 20% increased irrigation efficiency + 6% increased yield; 20% increased BoR conveyance efficiency; 20% increased onfarm BoR water cost.

economic benefits to agriculture. Figure 4 illustrates relatively modest economic benefits to agriculture of $9.5 to $27 million for increased levels of irrigation efficiency alone. Figure 5 illustrates that economic benefits can be much higher when the policy-induced irrigation technical change increases crop productivity. For the resource-efficiency policy-mix options (E1–E4), output-enhancing irrigation technical change would increase net economic returns to agriculture from $56 million to $167 million. However, given that the crop productivity increases assumed for E1–E4 (2% to 6%, respectively) are conservative, the economic benefits estimated here are probably also conservative.

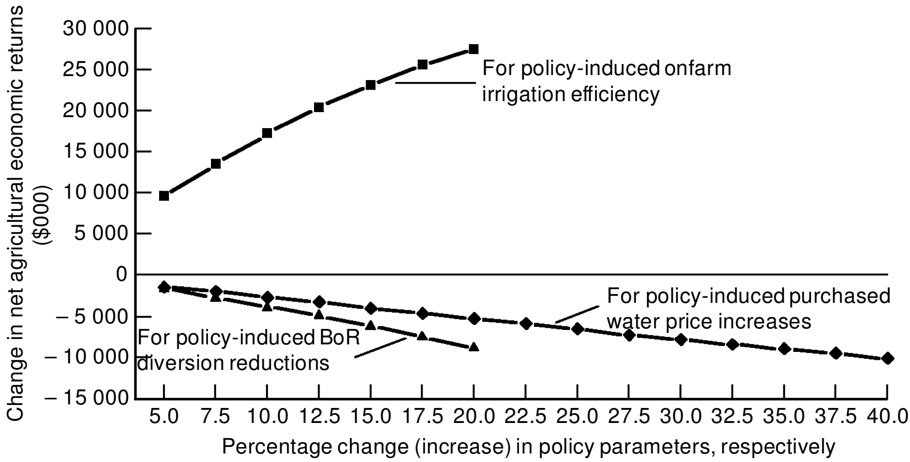

Figure 4. Regional agricultural economic (producer surplus) changes: regulatory versus conservation-incentive water policy choices, Pacific Northwest. *Key*: ■ onfarm irrigation efficiency; ◆ onfarm purchased water cost; ▲ reduced BoR diversions.

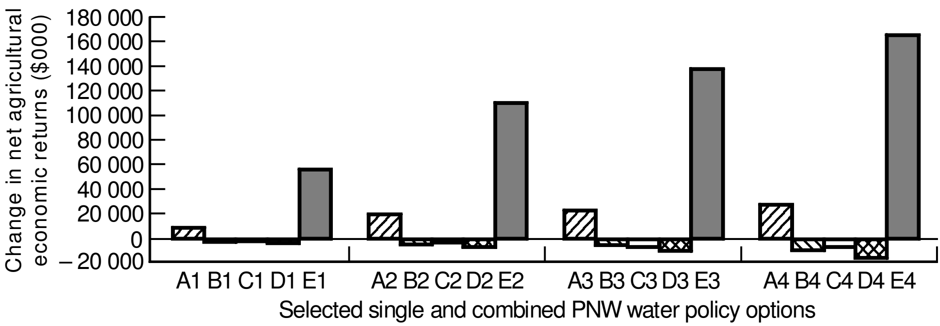

Figure 5. Regional agricultural economic (producer surplus) changes: selected single and combined water policy options, Pacific Northwest. *Note*: See Note, Figure 3, for policy parameter changes.

Even so, if increasing onfarm irrigation efficiency increases agricultural economic benefits, then why would farmers not adopt improved irrigation systems on their own? The answer is they do, but various economic and institutional impediments ensure that the pace of technical change is quite slow. Schaible *et al.* (1991) demonstrate that while irrigated farmers in the Pacific Northwest will continue to adopt improved irrigation technologies, producer-induced irrigation technical change is likely to be quite slow in the absence of conservation-incentive water-policy change. Financial, output-price and resource-availability risks at the farm level often prevent producers from realizing the benefits of improved irrigation efficiency on their own. In addition, beneficial use criteria, that is, 'use it, or lose it' criteria of western prior appropriation law, are believed to force farmers to face conservation disincentives to irrigation technical change. Conserved water rights are often not well defined. Institutional impediments to onfarm water conservation tend to promote stability with irrigators' initial investments.

From an economic perspective, then, Figures 2–5 suggest that PNW water policy reform that encourages the adoption of water-conserving irrigation technologies and improved water management would garner greater onfarm conserved water and, at the same time, increase economic returns to farmers. In addition, this analysis suggests the potential for a conservation-incentive policy focus to achieve regional water-quality goals for both surface and groundwater supplies. This policy approach may then help to fulfil both water quantity and quality objectives designed to satisfy water demands for the region's endangered aquatic species.

Agriculture's Minimum Willingness-to-accept Water-policy Change

The reality of western water-policy reform, however, is that implementation of conservation-incentive policies would be heavily influenced by agriculture's willingness-to-accept (WTA) policy change. Farmer economic losses (for example, for a regulatory or water-price policy), and the economic benefits of irrigation technical change, when normalized in terms of a unit of onfarm conserved water, identify aggregate average, agricultural minimum WTA values for water-policy change. These values represent the minimum values that would either compensate or induce producers to accept the policy change while making themselves no worse off. While actual policy implementation may require greater compensation than minimum WTA values (Innes, 1999), the estimates here provide a good basis for comparative economics across water policy perspectives.

Figures 6 and 7 identify significant differences in agriculture's minimum WTA water policy change between policy choices for the PNW. Figure 6 shows that producer minimum WTA values per unit of onfarm conserved water are relatively small, ranging from \$10 to \$25 when the policy emphasizes a single policy perspective and excludes potential crop productivity. Producer minimum WTA values decline for water price or irrigation technical change because of their conservation-incentive character, as opposed to a regulatory policy focus. However, Figure 7 indicates that when crop productivity increases are accounted for (options E1–E4), producer minimum WTA policy-induced onfarm conservation would initially average \$150 per acre-foot of conserved water for the PNW (option E1). At the margin, this value declines for the PNW to about \$97 per acre-foot of conserved water for a more stringently imposed resource-efficiency policy mix (option E4).

Figures 8 and 9 illustrate that significant regional variation exists in producer minimum WTA conservation-incentive water policy. When crop productivity potential is excluded (Figure 8), minimum WTA policy-induced irrigation technical change varies initially from \$15 per acre-foot of conserved water for Oregon, to \$37 per acre-foot for Idaho. At the margin, these values decline for higher levels of policy-induced conservation, but more significantly for Idaho than in Oregon or Washington. When crop productivity is accounted for (Figure 9), producer minimum WTA conservation-incentive water policy would initially range from \$96 per acre-foot of conserved water for Oregon (option E1), to \$150 per acre-foot for Washington, to \$208 per acre-foot of conserved water for Idaho. These values most probably explain in part the difficulty the US Bureau of

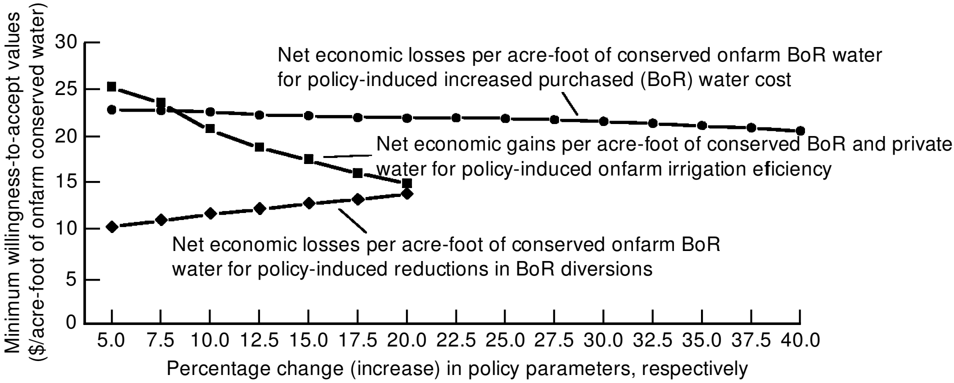

Figure 6. Producer minimum willingness-to-accept regulatory versus conservation-incentive water-policy choices, Pacific Northwest. *Key*: ■ onfarm irrigation efficiency; ● onfarm purchased water cost; ♦ reduced BoR diversions.

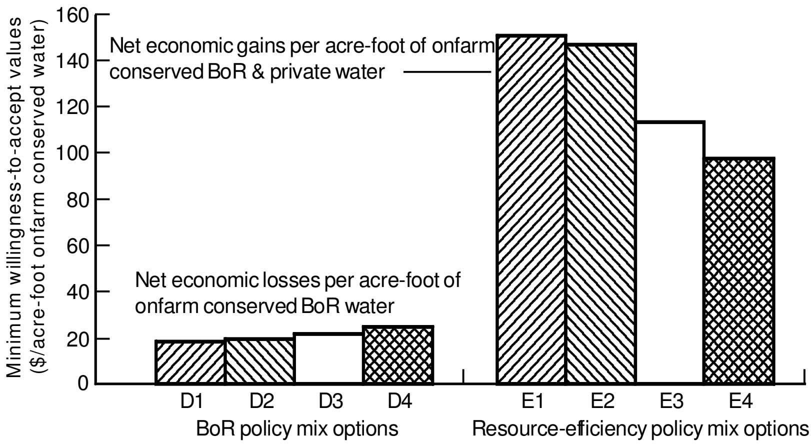

Figure 7. Producer minimum willingness-to-accept selected water policy-mix options, Pacific Northwest. *Note*: See Note, Figure 3, for policy parameter changes.

Reclamation has had in obtaining broad producer participation from the upper Snake River Basin in its flow augmentation programme for endangered salmon species. These results imply that initial conserved water supplies can be acquired only at a higher per unit price than average. BoR lease prices in the neighbourhood of $50 per acre-foot appear to be modest relative to producer-perceived values. However, at higher levels of policy-induced irrigation efficiency (option E4), producer minimum WTA additional induced-irrigation technical change declines to $67, $97 and $119 per acre-foot for Oregon, Washington and Idaho, respectively.

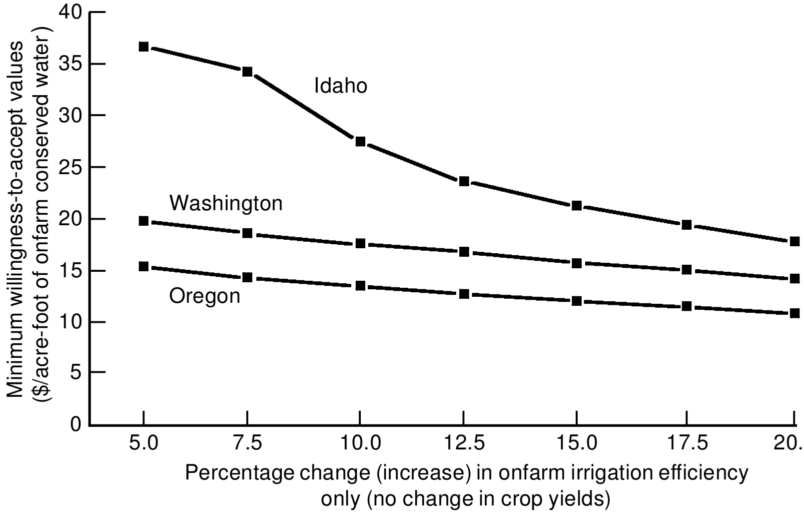

Figure 8. Producer minimum willingness-to-accept policy-induced irrigation technical change (increased onfarm irrigation efficiency): Idaho, Oregon, and Washington.

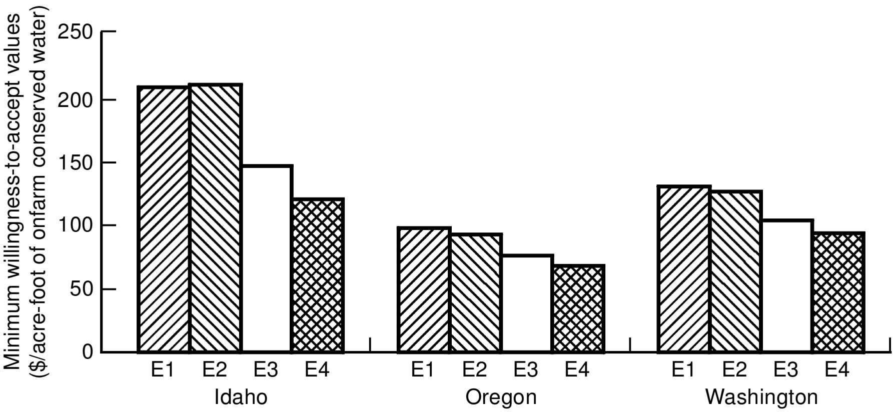

Figure 9. Producer minimum willingness-to-accept selected resource-efficiency policy-mix options: Idaho, Oregon, and Washington. *Note:* See Note, Figure 3, for policy parameter changes.

Summary and Conclusions

Numerous water policy choices exist to induce PNW agricultural water conservation. A primal-dual, multiproduct, normalized restricted-equilibrium economic framework provides, first, the ability to endogenize unique producer resource opportunity (adjustment) costs, and second, the ability to consider resource and output substitution possibilities simultaneously when evaluating either single or multiple water-policy perspectives. The amount of onfarm water conserved in the PNW would vary significantly across water-policy choices, and there would be either minimal economic cost, or modest to substantial economic gain to agriculture depending on the policy change. A conservation-incentive policy that encourages adoption of improved irrigation technologies and water management would generate substantial onfarm water conservation, but would also significantly increase net economic returns to agriculture whenever onfarm irrigation technical change also increases crop productivity. A water-price policy that increases farm-level purchased water costs for BoR-supplied water would generate the least amount of onfarm conserved water. While this policy reduces farm economic returns (producer surplus), the agricultural sector and/or society may still gain, depending on the allocation of the additional BoR water revenues. However, a regulatory policy that reduces diversions of BoR-supplied water is the most costly policy to agriculture. Water policy reform that integrates multiple water-policy perspectives provides decision makers with the greatest flexibility to do the most to achieve the multiple water-policy goals of water conservation, resource-use equity, surface and groundwater quality, and sustainable rural economies in the region. Conservation-incentive water policy, when integrated within balanced policy reform, has the greatest potential to allow agricultural water conservation to serve as a shared sacrifice across regional stakeholders, including concerns for endangered aquatic species, Native American rights, recreationists, power interests and sustainable rural agricultural economies.

The results of this analysis, along with those of Willis *et al*. (1998), suggest that conservation-incentive water policy would enhance the effectiveness of using Idaho's water bank to meet Lower Snake River flow needs for endangered aquatic species. However, both state and federal legal and institutional impediments exist which presently reduce the effectiveness of water-consevation policy (Moore, 1991; Wahl, 1987; NMFS, 1999). If water-conservation policies are to be effective in the Pacific Northwest, these impediments must also be addressed.

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